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Rev. 0

Work Plan for Phase III Feasibility Study 300-FF-5 Operable Unit

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management
Pacific Northwest National Laboratory for the
U.S. Department of Energy under Contract DE-AC05-76RL01830

United States
Department of Energy
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Richland, Washington 99352

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Summary

In 1996, a record of decision was issued for the 300-FF-5 Operable Unit on the Hanford Site in southeast Washington State. The record of decision identified interim actions for remediation of the contaminant plume beneath the site:

- Continued groundwater monitoring to determine how contaminant conditions may change with time.
- Institutional controls to limit the use of groundwater.

These interim actions have determined that uranium concentrations in the groundwater plume have been declining, but persist at concentrations above the drinking water standard (remediation goal). The rate of uranium contamination decrease is likely slow because some of the disposed uranium remains in the soil within the aquifer and just above the aquifer, and it is slowly being released into the groundwater. Therefore, re-evaluation of the remedy for uranium contamination is necessary because the rate of decrease in uranium concentrations is significantly different than the rate of decrease expected and used as a basis for the remedy selection in the current record of decision.

The re-evaluation of the remedy for uranium in the groundwater will be documented in the Phase III Feasibility Study, which will be the result of the characterization, modeling, and remediation feasibility analysis that are described in this work plan. This document presents the work plan to complete the Phase III Feasibility Study. In addition, Appendix A of this document summarizes the technology evaluation that has been conducted to date. The objectives of the Phase III Feasibility Study are to identify, develop, and select remedial actions that have the potential to (1) restore, to the extent possible, the 300-FF-5 groundwater aquifer to its highest and best beneficial use, and (2) reduce risk to human health and the environment. During the re-evaluation, the following elements will be considered for remedy of uranium in the 300 Area:

- Collect information about uranium adsorbed on vadose soil and aquifer solids to improve estimates of expected future changes in the concentration of uranium in groundwater.

- Determine the direction and flow rate of groundwater in the area to understand more completely how uranium moves through the aquifer.

- Determine uranium flux to the Columbia River.

- Determine ecological risk of uranium discharging into the Columbia River.

These elements will help decision makers understand the impact of natural attenuation and more active remedies that could be applied.

Re-evaluation of the uranium remedy will be conducted using a specific process that is consistent with the federal regulations associated with remedy selection (e.g., the CERCLA process). Based on the improved conceptual model for the plume, candidate technologies that have the potential to reduce the input of uranium into the groundwater (i.e., reduce the amount of uranium that is being released from the

soil into the groundwater) or reduce the groundwater concentration in other ways will be investigated as the first step in the evaluation process. Each candidate technology will be assessed in terms of its feasibility for application to the 300 Area uranium plume based on existing information about application of the technology at other sites and information about the technology in the scientific literature. Additional evaluation of a promising candidate technology may involve laboratory treatability tests with 300 Area samples and/or field treatability testing, as appropriate. During the technology assessment process, potential combinations of multiple technologies will be considered. Using the information from this technology assessment and the improved conceptual model information, potential remedial alternatives (i.e., specific, comprehensive remediation approaches for the 300 Area plume) will be defined. The cost and performance of potential remedial alternatives will be compared to the cost and performance of the current remedy (natural attenuation) using a feasibility study process as defined by federal regulation.

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1.0 Introduction

When the Phase III Feasibility Study is complete, it will supplement the earlier evaluation of remedial actions conducted within the *Phase I and II Feasibility Study Report for the 300-FF-5 Operable Unit* (DOE 1994a) and the detailed analysis of remedial alternatives for groundwater remediation in the *Remedial Investigation/Feasibility Study Report for the 300-FF-5 Operable Unit* (DOE 1995b). The Phase III Feasibility Study will use an updated conceptual model, which includes analysis of recent groundwater concentration data, laboratory investigations, and numerical modeling studies. The earlier feasibility studies focused on the saturated regime of site groundwater and used a conceptual model based on less information.

The selected interim remedies for groundwater in the 300 Area adopted by the 300-FF-5 record of decision (ROD 1996) were (1) “Institutional Controls to prevent human exposure to groundwater” and (2) “Groundwater monitoring to verify modeled predictions of contamination attenuation and to evaluate the need for active remedial measures.” The contaminants of concern in the groundwater addressed by the interim remedial actions specified in the record of decision were uranium, trichloroethene, and 1,2-dichloroethene.

The Phase III Feasibility Study will focus only on uranium contamination in the 300 Area. Based on the groundwater monitoring data, uranium is the only groundwater constituent requiring this additional action. The existing remedy (natural attenuation) is performing acceptably for all other groundwater constituents. A detailed analysis for all of the monitored groundwater constituents in the 300-FF-5 Operable Unit is presented by Peterson et al. (2005).

Subsequent groundwater monitoring, which was reported in annual reports (e.g., Hartman et al. 2004), documented an unexpected persistence of dissolved uranium concentrations in the groundwater under the 300 Area. Uranium concentrations have been declining in the groundwater plume over the last 10 years, but persist at concentrations above the drinking water standard (remediation goal). The rate of uranium contamination decrease is likely slow because some uranium remains in the soil within the aquifer and just above the aquifer, and it is slowly being released into the groundwater. As a consequence, re-evaluation of the remedy for uranium contamination is necessary because the rate of decrease in uranium concentrations is significantly different than the rate of decrease expected and used as a basis for the remedy selection in the current record of decision (ROD 1996).

The re-evaluation of the remedy for uranium in the groundwater will be documented in the Phase III Feasibility Study, which will be the result of the characterization, modeling, and remediation feasibility analysis that are described in this work plan. The objectives of this re-evaluation are to identify, develop, and select remedial actions that have the potential to (1) restore, to the extent possible, the 300-FF-5 groundwater aquifer to its highest and best beneficial use, and (2) reduce risk to human health and the environment.

Planned activities associated with re-evaluation of the remedy for uranium include collecting quantitative information about the key elements of the conceptual model shown in Figure 1. Because uranium adsorbed on soil can be released into the groundwater, information is needed to assess the nature and extent of the uranium adsorbed on soil that can contact the groundwater. This information will provide an improved basis to estimate the expected future changes in the concentration of uranium in groundwater, and therefore, improve the estimate for the expected lifetime of the plume with a natural attenuation remedy. The nature and extent of the uranium adsorbed on soil also impacts the performance of other more active remedies that may be considered for the plume. Additionally, it is necessary to develop an improved understanding of groundwater flow patterns and how uranium moves through the aquifer. The characteristics of uranium movement in the aquifer significantly impact the performance of natural attenuation and other more active remedies. Risk to receptors must also be considered when selecting a remedy. Thus, the ecological risk from uranium discharging into the Columbia River needs to be understood as part of the basis for re-evaluating the remedy.

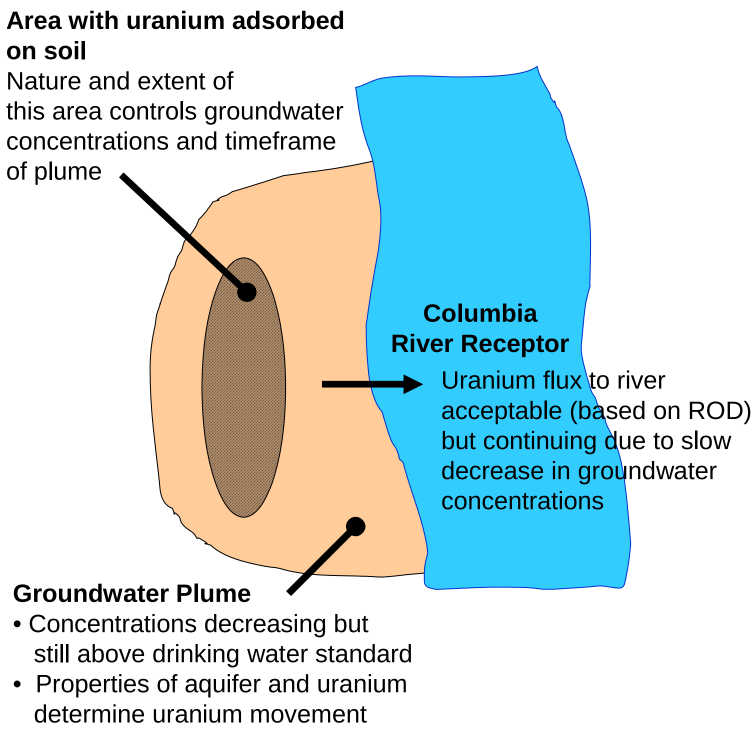

Figure 1. Simplified Conceptual Model of the 300 Area Uranium Plume

Re-evaluation of the uranium remedy will be conducted using a specific process that is consistent with the federal regulations associated with remedy selection (e.g., the *Comprehensive Environmental Response, Compensation, and Liability Act* [CERCLA] process, as amended by the *Superfund Amendments and Reauthorization Act*). Based on the improved conceptual model for the plume, candidate technologies that have the potential to reduce the input of uranium into the groundwater (i.e., reduce the amount of uranium that is being released from the soil into the groundwater) or reduce the groundwater concentration in other ways will be investigated as the first step in the evaluation process. Each candidate technology will be assessed in terms of its feasibility for application to the 300 Area uranium plume based on existing information about application of the technology at other sites and information about the technology available in the scientific literature. Additional evaluation of a promising candidate technology may involve laboratory treatability tests with 300 Area samples and/or field treatability testing, as appropriate. During the technology assessment process, potential combinations of multiple technologies will be considered. Using the information from this technology assessment and the improved conceptual model information, potential remedial alternatives (i.e., specific, comprehensive remediation approaches for the 300 Area plume) will be defined. The cost and performance of potential remedial alternatives will be compared to the cost and performance of the current remedy (natural attenuation) using a feasibility study process as defined by federal regulation.

2.0 Site Background and Conceptual Model for the 300-FF-5 Operable Unit

In February 1943, approximately 1,618 square kilometers (625 square miles) of remote, semi-arid shrub steppe near the small town of Hanford, Washington, was chosen by the War Department as the site for the manufacture of plutonium for the Manhattan Project of World War II—the construction of the first atomic bombs. Several areas on the property were designated for various functions in the plutonium production process. The 300 Area, adjacent to the Columbia River immediately north of the town of Richland, was developed with manufacturing and industrial facilities necessary to fabricate uranium fuel for plutonium production reactors and laboratory facilities designed to test materials related to plutonium production processes (Young and Fruchter 1991). The manufacturing and laboratory operations that produced waste began in 1944 and ended in the 1980s.

Groundwater beneath the 300 Area contaminated from liquid or solid waste releases or waste deposits associated with the 300 Area is defined as the 300-FF-5 Operable Unit. The unit includes both groundwater and solids that comprise the aquifer. The water table continuously fluctuates near the Columbia River with changing river elevations. Nominally, depth to water in the 300-FF-5 Operable Unit ranges between 8 and 17 meters (26 to 56 feet) below ground surface depending on topographical location. The 300-FF-5 aquifer is unconfined and flows through glacially deposited gravels and sands. Groundwater flow and direction is very dynamic near the river, but generally flow is west to east and toward the river. The aquifer flows within an upper layer called the Hanford formation and a lower stratum called the Ringold Formation. The aquifer solids in the Hanford stratum of the aquifer range in size from pebble-cobble gravel to boulders as large as 1 meter (3.3 feet) and extend below the water table between 1.5 to 9 meters (5 to 30 feet). The deeper Ringold stratum extends down another 12+ meters (40+ feet) and consists of interstratified deposits of sand, silt, clay, and gravel. Whereas the upper Hanford strata is very permeable with flow velocities as high as 10 meters (32.8 feet) per day, the deeper Ringold stratum is moderately permeable with flow velocities 2 to 3 orders of magnitude less.

As described by Peterson et al. (2005), the 300 Area process ponds (NPP and SPP) received waste between 1943 and 1975. In addition, waste was discharged to the subsurface between 1975 and 1985. The chemical characteristics and quantities of this waste are complex but poorly documented. A major portion of the total waste stream originated from nuclear fuels fabrication. The waste from nuclear fuels fabrication included basic sodium aluminate solutions and acidic copper /uranyl nitrate solutions. Primary chemical contaminants deposited to the process ponds included uranium (33,566 to

58,967 kilograms [74,000 to 130,000 pounds]), copper (241,311 kilograms [532,000 pounds]), fluorine (117,026 kilograms [258,000 pounds]), aluminum (113,398 kilograms [250,000 pounds]), nitrate (2,060,670 kilograms [4,543,000 pounds]) and large volumes of acid and base.[1] Initially acid conditions of the copper/uranyl nitrate fuel fabrication waste allowed percolation of copper and uranium into the vadose zone beneath the ponds and into the 300-FF-5 Operable Unit aquifer. Both Cu(II) and U(VI) adsorb strongly to minerals in aquifer solids near neutral pH range. Copper and uranium also tend to precipitate as hydroxide and carbonate phases as base is added.

Later pH manipulation of the waste pond waters was conducted with the addition of base. The neutralization of the pond waters decreased migration of the Cu^{2+} and U^{6+} through a combination of precipitation and adsorption in both the unsaturated vadose zone and saturated aquifer sediments. Where alkaline conditions in the groundwater occur due to the base addition above, uranyl carbonate complexes have formed which become mobile in contrast to copper. Consequently engineered liquid waste disposal facilities, the underlying vadose zone, and the uppermost aquifer have been contaminated by uranium (Young et al. 1990; Young and Fruchter 1991; DeFord et al. 1994). The greatest impacts on groundwater from disposal of waste containing uranium probably occurred during the 1950s and 1960s, when effluent was directed to the 307 trench, the north and south process ponds, and during the 1970s and 1980s to the 300 Area process trenches. Some uranium in the groundwater plume may also have been widely distributed in the past during periods of unusually high water-table conditions. As conditions returned to more normal levels, groundwater containing uranium was left behind in the less than fully saturated capillary fringe above the water table.

A groundwater plume has been present beneath the 300 Area since disposal operations started. Its persistence indicates some level of re-supply from the vadose zone via mechanisms not yet clearly defined, because the rate of groundwater movement appears to be sufficient to have moved the plume away from the area in the absence of re-supply. Following excavation of the most contaminated waste disposal sites and adjacent soil during the period 1995 to 2004, some uranium remains in the underlying vadose zone. Uranium in groundwater is currently transported to the Columbia River under natural hydrologic flow conditions, where it discharges into the river system and is dispersed via additional transport pathways (e.g., the free-flowing stream, biota and food chain, and sediment). Uranium is also being removed from the aquifer via a water supply well that has provided water for aquarium operations at the 331 Building since 1982.

Uranium in the 300 Area environment represents an actual or potential risk via the following pathways:

- Radiation dose to humans at the ground surface
- Radiation dose and ingestion hazards to terrestrial biota
- Ingestion hazards to humans who use groundwater as drinking water
- Human and biotic exposure to uranium-contaminated water at the river shore
- Uptake of uranium by aquatic organisms that use the interface as habitat

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[1] JE Szecsody (Pacific Northwest National Laboratory), draft paper on 300 Area Conceptual Model Rev. 0, dated December 2004.

The risk associated with some of these pathways has been significantly reduced by source removal actions during the period 1995 to 2004. Human health risks associated with groundwater have been managed by institutional controls on groundwater use. Recent efforts have been undertaken to better define contaminant distribution in various media along the shoreline (e.g., Patton et al. 2003), and risk assessments are underway for the Columbia River Corridor, including the 300 Area segment (DeFord et al. 1994).

Key Components of Conceptual Site Model for Uranium

Figure 2 is a generalized cross section showing a former liquid waste disposal facility, the uranium plume, and the Columbia River (adapted from Lindberg and Chou 2001, Figure 5.1). For this report, five zones are identified as having significance for anticipating the distribution and mobility of uranium contamination:

- Zone 1 represents the waste site and adjacent soil that has been removed as part of source remedial actions. While initially a conduit for supplying uranium to the subsurface, no future impact to the groundwater will occur. Backfill and surface cover materials will influence the degree that natural precipitation or water from human activities (e.g., irrigation) will infiltrate.

- Zone 2 is the vadose zone between the deepest part of the source excavation and the capillary fringe associated with the groundwater table. Relatively high concentrations of uranium are likely to have migrated through this zone during operations. Limited sampling within and beneath excavated waste sites indicates that some amount of uranium remains sorbed to sediment in this zone.

- Zone 3 is a zone defined by the maximum elevation of the capillary fringe associated with the water table and the minimum water-table elevation. During periods of unusually high water-table elevations (because of high river-stage conditions), uranium-contaminated groundwater would move into the lower vadose zone. When the water table returned to normal, some uranium would have been left behind in pore fluid and retained on soil particles, thus remaining as a potential source for plume re-supply if unusually high water-table elevations return.

- Zone 4 is the uppermost hydrologic unit through which uranium migrates toward the Columbia River. During migration, dissolved uranium interacts with aquifer solids to sorb or desorb, depending on geochemical conditions.

- Zone 5 is a highly dynamic zone of interaction between groundwater and river water that infiltrates the banks and channel substrate to varying degrees, depending on river stage. Geochemical conditions change rapidly within this zone because of the contrast in certain characteristics of groundwater and river water. Dilution of contaminants in groundwater typically occurs in this zone, prior to the ultimate discharge of groundwater into the river system.

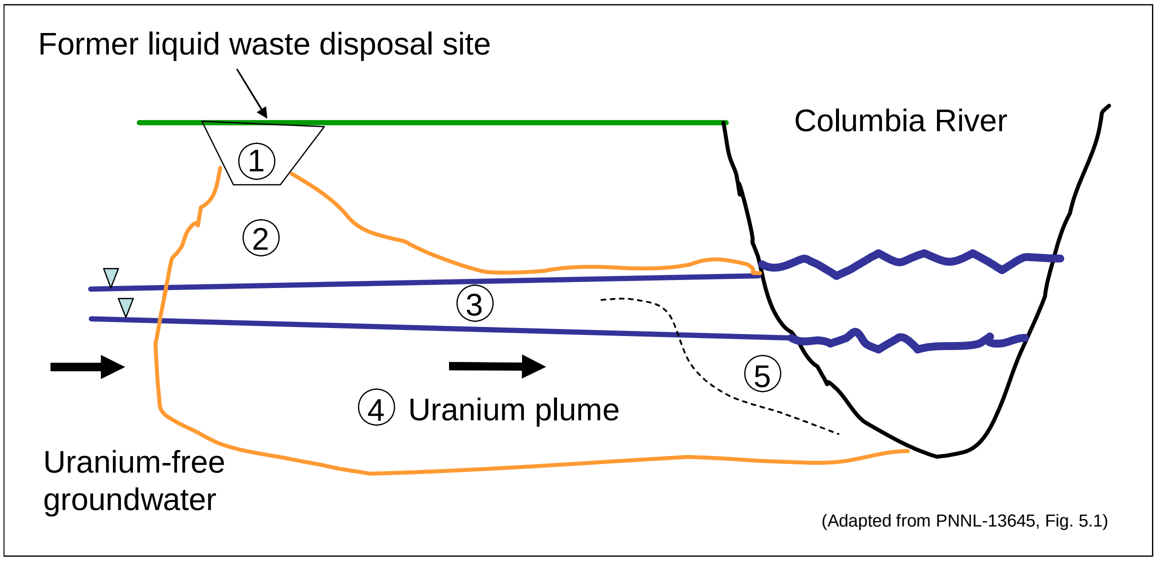

Figure 2. Generalized Cross Section of the 300 Area

The features and processes in each of the zones described in Figure 2 influence the level of contamination and how it changes with time. Even though the basic elements of the uranium distribution and the plume's migration over time have been described in initial site models (e.g., DOE 1995b), additional details on certain features and processes are needed to provide an appropriate technical basis for re-evaluating the current interim remedy. An improved estimate for the inventory of uranium in each zone is key among the information needed.

In summary, the major issues associated with a conceptual site model for the uranium plume beneath the 300 Area involve (1) how much uranium from waste disposal operations remains in the environment; (2) how that amount varies with time; (3) if decreasing, when will the level reach criteria that are acceptable; and (4) is uranium causing an unacceptable impact to human health and biota. Currently, the phrase "acceptable criteria" means groundwater at concentrations lower than the EPA drinking water standard of 30 µg/L. No water quality criteria for the protection of freshwater organisms have yet been listed for uranium, so the 30-µg/L value is used by default for groundwater at discharge locations associated with the Columbia River.

The following subsections provide descriptions for features and processes associated with uranium contamination in the 300 Area and are intended to provide decision makers (e.g., DOE, EPA, and Washington State Department of Ecology [Ecology]) with the technical basis to re-evaluate the remedy for the 300 Area uranium plume. These descriptions also establish a framework for numerical models that are used to estimate conditions away from points of observation and for predicting future conditions. The characteristics in each of the five zones shown in Figure 2 will determine the suitability of various technologies considered in the feasibility study to reduce uranium concentrations in groundwater.

Though not published at the time of the 300-FF-5 record of decision (ROD 1996), the selected remedy in that decision can be interpreted in the framework of the U.S. Environmental Protection Agency (EPA) *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites* (EPA 1999, OSWER Directive 9200.4-17P), hereafter referred to as the "OSWER MNA Directive." It is also appropriate to consider whether continuation of a monitored natural attenuation (MNA) remedy would be reasonable based on the current information about the 300-FF-5 contaminants of concern and the OSWER MNA Directive. Conclusions from a review of the 300-FF-5 record of decision (ROD 1996) and the current information for the uranium plume in the 300 Area are listed below (Peterson et al. 2005):

- The selection of the 1996 300-FF-5 record-of-decision remedy of monitoring with institutional controls appears to have been consistent with MNA implementation.

- MNA should be considered as a continuing remedy as part of re-evaluating the remedy for the 300-FF-5 Operable Unit.

It was also concluded that additional work is needed to fully evaluate MNA as a remedy in conjunction with consideration of other potential remedies. Specifically, the MNA evaluation requires the following:

- Additional characterization data to verify or revise the new site conceptual model for the uranium plume, in particular with respect to the distribution of uranium in soils that can contact the groundwater.

- Numerical modeling to estimate the uranium concentration over time within the plume and discharging into the river.

These information needs are incorporated into this work plan.

3.0 Work Plan Objectives

The overall objective of the work plan for the Phase III Feasibility Study is to re-evaluate the remedy for the uranium plume in the 300-FF-5 Operable Unit. The ultimate objective of the Phase III Feasibility Study is to select remedial actions that have the potential to (1) restore, to the extent possible, the 300-FF-5 groundwater aquifer to its highest and best beneficial use, and (2) reduce risk to human health and the environment. Activities described in the work plan will update and improve the technical basis for re-evaluating the remedy and conduct the evaluation according to CERCLA guidelines. Specific objectives associated with these activities are listed below:

1. Obtain information to assess the nature and extent of area with uranium adsorbed on soil and provide a better estimate of likely expected changes of groundwater concentration (duration of plume).

2. Obtain information and develop an understanding of groundwater flow patterns to better understand the movement of uranium through the aquifer.

3. Update the risk assessment using new information.

4. Assess technologies that can reduce the input of uranium into the groundwater.

5. Update the conceptual model

6. Assemble and evaluate remediation alternatives based upon characterization that will be conducted in the first four objectives. This is the essence of the feasibility study. The feasibility study will be conducted in accordance with the CERCLA process and will compare the alternate remedial approaches to the current remedy (natural attenuation).

4.0 Work Plan Elements

The following elements describe the scope of work that will be conducted to address the objectives of the work plan.

4.1 Schedule

The schedule for the work plan elements is shown on Figure 3. Work on Phase III Feasibility Study for the 300-FF-5 Operable Unit has been ongoing since early 2004. The schedule in Figure 3 focuses on the work plan elements that will be conducted after March 31, 2005. The final deliverable associated with this work plan and schedule is a draft Phase III Feasibility Study in May 2007.

4.2 Limited Field Investigation Activities

As described in the following sections, additional characterization information will be collected to improve understanding of the nature and extent of the subsurface uranium contamination.

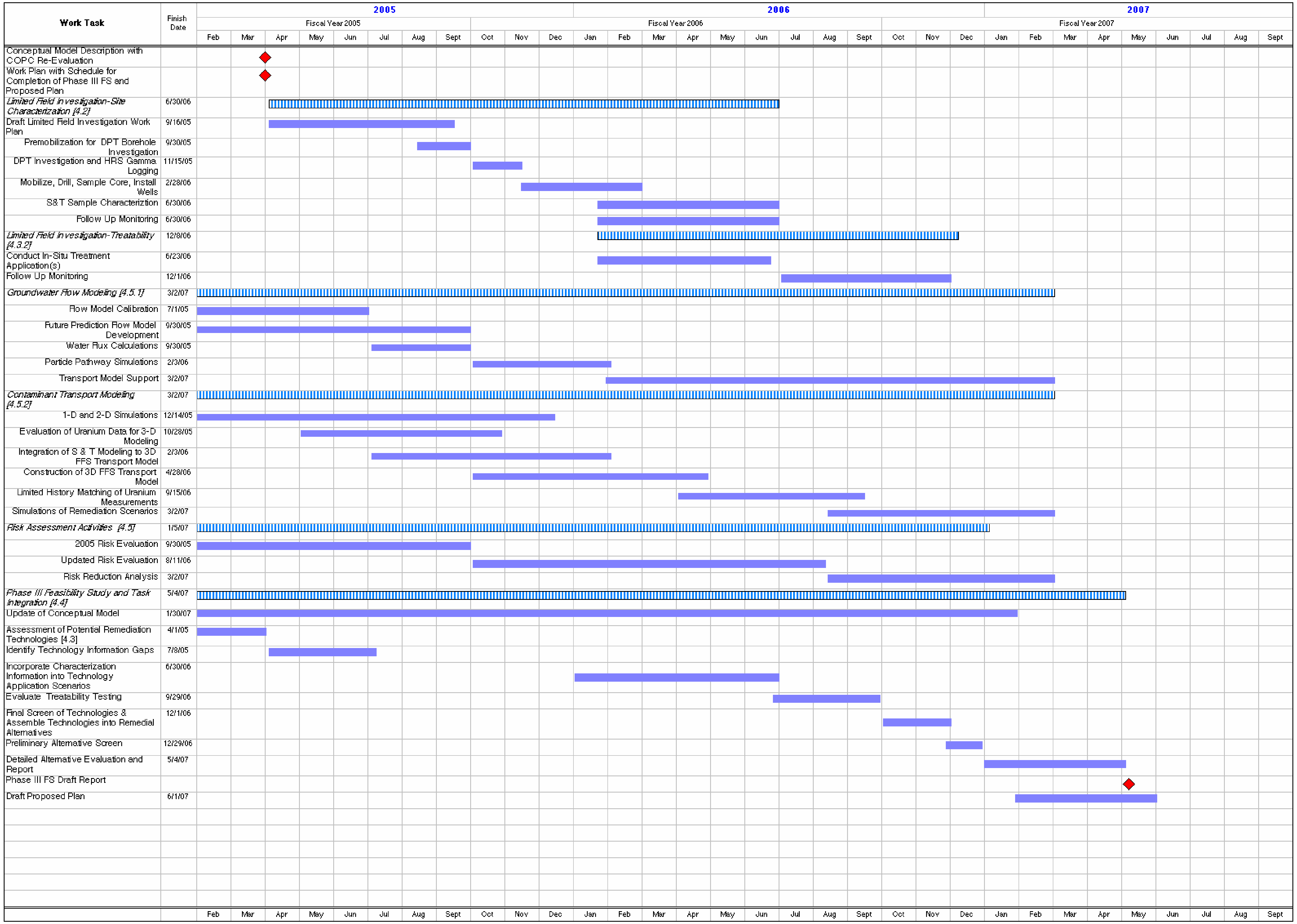

Figure 3. Work Plan Schedule for 300-FF-5 Operable Unit

4.2.1 Characterization Needs

Current information does not adequately describe the quantity, location, and geochemical context of the uranium contamination affecting the 300 Area groundwater. Specific unknowns requiring further characterization include location of adsorbed or leachable uranium that can continue to contaminate groundwater. Also, the total quantity or inventory of available uranium to the groundwater system is presently unknown. The hypothesis that uranium is adsorbed or precipitated in sediments above the nominal water table (i.e., smear zone) requires verification. Characterization of the nature of uranium and its distribution beneath the former disposal ponds and trenches is required. In addition, it is not known whether localized releases from 300 Area process buildings (hot spots) impact groundwater quality. Therefore, further site characterization is required.

4.2.2 Limited Field Investigation Plan

A limited field investigation work plan will be prepared to describe the data quality objectives and details for the field investigation procedures and treatability test plan. A draft of the plan will be completed in September 2005. Sections 4.2.2.1 and 4.2.2.2 provide a summary of the elements that will be described in detail in the limited field investigation work plan.

4.2.2.1 Limited Field Investigation

Initial characterization will better locate and define the extent and nature of contamination. The characterization effort will consist of a drilling, logging, and sampling program along transects through former disposal areas and other areas of concern. Information collected in this investigation program will allow refinement of the site conceptual model and support formulation of remediation strategies. The field investigation will also provide important input to the groundwater modeling effort.

4.2.2.2 Treatability Investigation

A second purpose of the field investigation is to provide the information necessary to evaluate candidate technologies. This performance evaluation of technologies will be conducted using core or soil samples collected during the characterization investigation in bench-scale investigations. Also, where appropriate, pilot testing of in situ treatment technologies will be conducted using wells that will be completed at locations identified in the characterization investigation. The testing will be designed according to the location, stratigraphy, hydrologic conditions, and properties of the uranium contamination.

4.2.3 Limited Field Investigation Procedures

The field investigation will be designed to determine the lateral and vertical extent of uranium contamination in soil near former disposal sites and at other areas of concern. A phased approach is planned. The initial phase will consist of multiple exploratory borings using relatively rapid direct push technology (DPT) to survey the subsurface of the 300 Area. The primary objectives of the initial DPT survey are to identify and map zones of elevated uranium concentrations and possibly sample soil with sorbed uranium. Follow-up installation of wells may be conducted using the results of this initial survey.

This approach will temporarily install boreholes at selected locations of interest. The DPT would drive either 16.8- or 17.8-centimeter (6 5/8- or 7-inch outside-diameter steel casing to the water table or slightly deeper; borehole depths would range from around 9 meters (30 feet) to as deep as 18 meters (60 feet). Once the desired depth is reached, an optional polyvinyl chloride (PVC) casing will be placed in the borehole and the drive casing pulled back to expose the lower PVC casing for spectral gamma logging. This option allows greater gamma signal capture than through steel casing, resulting in higher sensitivity and improved data analysis. Spectral gamma data will be collected using a sensitive spectral gamma-logging probe (70% germanium). The probe will be lowered to the bottom of the borehole and logging will progress in a stop-and-acquire mode every 0.3 meter (1 foot) of depth, with an interval count rate between 100 and 200 seconds/interval. The data will be processed and reported by the selected logging contractor. Results will delineate both natural and manmade uranium and related isotopes. The data can provide the vertical location and concentration of detectable U-235 in the vadose zone.

The rapid geophysical logging and down-hole radioactive surveys will enable expedited mapping of subsurface uranium. As the survey proceeds, the survey plan will be modified in the field to incorporate findings from prior locations of the survey.

The site conceptual model will be updated according to the findings of the exploratory survey. Particular attention will be focused on the presence of uranium deposits near the water table and near infiltration zones. A well construction plan will be developed to locate up to 12 wells that will be installed. Prior to well drilling, a localized conceptual model of expected geology and hydrology will be formulated at each well location. During the well drilling, actual conditions encountered will be validated with the expected conceptual model. Deviations from expectations will be carefully studied and analyzed to modify the drilling plan where appropriate. The sequencing of the wells will be carefully managed so as to both provide injection and possible extraction wells along with local process monitoring wells for field pilot testing of selected remediation technologies. Sediment samples will be collected during well installation for potential use in laboratory experiments and for confirmatory characterization of the uranium concentration. The Limited Field Investigation Work Plan that will be developed prior to the field investigation will prescribe the type, number, quantity of samples collected. Chemical analyses, geo-hydrologic property determination and other testing protocols for the samples collected will also be specified in the Limited Field Investigation Work Plan.

4.3 Assessment of Potential Remediation Technologies

Preliminary identification and screening of technologies that could be applied to remediate uranium in groundwater in the 300-FF-5 Operable Unit has been completed. This short list used the criteria of technical implementability to eliminate technologies that are clearly not suitable for the 300 Area application. Appendix A describes this analysis. The technology screening process will be completed as part of the feasibility study task described in the following sections. It is necessary to obtain the additional characterization information identified in the work plan and update the conceptual model before the screening can be completed.

4.4 Phase III Feasibility Study

The feasibility study process within the context of CERCLA consists of the development and screening of remedial action alternatives and a detailed analysis of a limited number of the most promising options to establish the basis for a remedy selection decision. The feasibility study process assumes a dynamic interchange of information with site characterization work. Feasibility study analysis relies particularly on the definition of the nature and extent of contamination, which can only be obtained from on-site field investigations (EPA 1988).

The feasibility study process is a multi-step sequence:

- Inventory of applicable technologies and management strategies.

- Preliminary evaluation of technologies to determine appropriateness.

- Assemblage of selected technologies into potential remediation alternatives that could be deployed to control or treat contaminants of concern in each medium or regime (groundwater, saturated soil, unsaturated soil). Remediation alternatives may consist of a single distinct technology or multiple technologies, deployed sequentially, at one or multiple locations and/or vertical regimes.

- Initial screening evaluation of remediation alternatives with regards to:
  - Short- and long-term effectiveness and reductions achieved in toxicity, mobility, or volume
  - Implementability including technical and administrative feasibility
  - Economic evaluation of total life cycle cost.

- Detailed analysis of selected remedial alternatives relative to nine evaluation criteria mandated by statutory directive and regulatory guidance.

- Comparative analysis of the candidate remediation alternatives with each other using the nine evaluation criteria to identify tradeoffs among options.

- Clear, concise documentation of the prior steps in a Feasibility Study Report to enable the decision makers to understand distinctive advantages and disadvantages of each alternative so that a remedy may be selected and implemented.

4.4.1 Update of Conceptual Model

The conceptual model for the site is the organizational information framework for describing geology, hydrogeology, geochemistry, and contaminant characterization of the 300-FF-5 site will be continually refined by the information generated from the other work plan elements. In parallel with the detailed sequence of sampling, analysis, modeling, and feasibility study outlined in this plan, separate directed engineering analysis of uranium inventory and transport in the soil and groundwater will be used to “bound” the conceptual model. This simple, less specific, order-of-magnitude engineering analysis will allow remedy-focused overview and interpretation of the overall feasibility study program.

As the first step in the feasibility study, an updated conceptual model for the 300 Area uranium plume will be developed that incorporates the results of the previous field investigation, modeling, and risk assessment efforts. This updated conceptual model will provide the framework for the subsequent feasibility tasks associated with remedial alternative development and evaluation.

4.4.2 Treatability Investigation

Based on screening of candidate technologies (preliminary screening described in Appendix A), there may be promising technologies for uranium remediation that require additional site-specific evaluation to determine if they are appropriate to include as part of a remedial alternative. For technologies in this category, treatability testing may be conducted. As appropriate, treatability testing will be conducted in the laboratory at the bench-scale or in the field in a pilot test.

Individual promising technologies may have particular strengths and weaknesses and be applicable to certain geochemical and site conditions. The treatability studies will be designed to verify whether a process option can meet the operable unit's cleanup criteria and to estimate the cost associated with use of the technology. The testing will be configured to develop design parameters, determine operation and maintenance requirements, as well as demonstrate process effectiveness for the specific site application. The results should allow packaging and configuration of the evaluated technology with other technology or remediation actions into a formal remediation alternative that can be carried forward into the feasibility study evaluation. The treatability testing results should allow estimation of costs for full-scale implementation of the technology in a remedial alternative deployment within accuracy of +50/-30 percent, as required for the feasibility study economic analysis.

Treatability testing will be conducted using site-specific sediments collected during the limited field investigation or in the field at a location identified as being applicable to the technology during the limited field investigation. Laboratory testing will be conducted with the site-specific sediments at a bench scale (e.g., soil column studies) to determine design, cost, and performance information at a scale appropriate for scale-up of the information to field application. It is anticipated that field tests will consist of a small pilot-scale test focusing on application of the technology at a single well surrounded by multiple monitoring wells. This type of field test configuration is small enough to enable detailed monitoring of the process and can provide design, cost, and performance information.

For both laboratory and field treatability tests, particular attention will be applied to uranium speciation, redox conditions, and major cations and anions because these are important to the behavior of uranium in the subsurface. Soil and sediment characterization will include collection, particle size distribution, and pore water testing of soils encountered in well installation. For field tests, a complete hydrogeologic assessment of the test area will be conducted including velocity profiling, pump tests, and short-term and longer-term water-level monitoring. The test area of the aquifer will be modeled so as to provide an interpretive tool for conducting and analyzing the test.

4.4.3 Feasibility Study

The feasibility study will be conducted in two phases. In the first phase, a conceptual design, an estimate of remediation performance, and a cost estimate will be developed for five to eight alternatives assembled from technologies and management strategies resulting from the technology screening and treatability investigations. Consistent with Chapter 4 of the *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988), a screening-level assessment of the alternatives will be conducted to select the most promising alternatives using CERCLA screening criteria of implementability, effectiveness, and cost.

In the second phase, detailed cost and technical analyses for the most promising alternatives will be conducted to select a preferred remedy based on the nine evaluation criteria prescribed by the CERCLA feasibility study process. This detailed analysis will include a preliminary design for the preferred remedy. The evaluation criteria are ordered into three groups based on the function of the criteria in remedy selection. The **threshold criteria** are most important in the evaluation and relate to statutory requirements that each alternative must satisfy in order to be eligible for selection and include the following:

- Overall protection of human health and the environment
- Compliance with applicable and relevant and appropriate requirements (ARARs)

Five technical **primary balancing criteria** will be used to evaluate each alternative according to:

- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume through treatment
- Short-term effectiveness
- Implementability
- Cost

Two **modifying** criteria will be assessed formally after the public comment period:

- State of Washington acceptance
- Community acceptance

However to the extent they are known, they will be factored into the recommendation of the preferred alternative in the report.

For the initial alternative screening portion of the feasibility study, the design for remedy alternatives will be conceptual, not detailed. A draft of the Phase III Feasibility Study report documenting the detailed analysis of the final remedial alternatives will be prepared. The report will include a tabular presentation comparing the alternatives according to the nine feasibility study criteria. Conceptual and preliminary design details such as

- Equipment definition
- Process flow diagrams
- Approximate quantities, sizing, and materials of construction
- Capital and construction cost estimates will be presented

The report will include a discussion of the implementation and construction as well as operation and maintenance considerations for the final alternatives. Future monitoring, waste disposal, safety and health, permitting, and regulatory considerations will also be addressed in the report.

4.5 Groundwater Flow and Contaminant Transport

Numerical modeling of groundwater flow and contaminant transport is necessary to better understand the movement of uranium through the aquifer and to provide a better estimate of likely expected changes of uranium concentration over time. The primary objective of the modeling is to calculate the flux of uranium throughout the groundwater flow system at the 300-FF-5 Operable Unit occurring as a result of changing river conditions. Initially, the current conditions will be modeled followed by more complex modeling techniques to simulate the effects of remediation alternatives. The approach and methodology will be detailed in a Modeling Simulation Plan that will be prepared concurrent to the limited field investigation work plan. Numerical modeling will consist of two components – flow modeling and contaminant transport modeling as described below.

4.5.1 Groundwater Flow Modeling

Groundwater flow modeling will be conducted to better understand the groundwater flow patterns in the 300 Area including groundwater flux through areas of soil contamination and groundwater flux to the Columbia River. The following tasks will be completed as part of this groundwater flow modeling effort.

4.5.1.1 Flow Model Calibration

Estimated hydraulic properties of Hanford and Ringold units will be input to a three-dimensional, numerical simulation. Results from the numerical simulation will be matched to an extensive set of real water-level measurements collected hourly from a network of wells during the period from 1991 through 1993 (Campbell 1994). Simulations using a range of hydraulic parameters for these main units will be assessed based on calculated residuals (simulated value – measured value) for individual wells. The calibration approach will be manual (i.e., not automated). Three hydraulic property distributions will be tested: (1) single values for the main Hanford and Ringold gravel units, (2) main units sub-divided into zones with different properties (based on residual analysis), and (3) stochastic distribution of hydraulic properties based on geostatistical analysis of physical property measurements from soils collected during well drilling in the area (e.g., Schalla et al. 1988; Swanson 1992). The hydraulic properties from the model that produces the best fit of the hydraulic head data during this simulation period (1991 to 1993) will be used in subsequent modeling efforts as described in the following sections.

4.5.1.2 Future Prediction Flow Model Development

A groundwater flow model will be developed for use in future predictions based on the hydraulic properties determined from the calibration process (Section 4.5.1.1). This model will represent conditions in the future for recharge for given land-use scenarios, other water sources (e.g., Richland Well Field), and water sinks (e.g., pumping). The eastern boundary of the model, which uses the Columbia River stage, will be cycled through the historical period since the operation of McNary Dam (1957) based on simulated river stages using a Columbia River model (e.g., MASS1 or MASS2).

4.5.1.3 Water Flux Calculations

Simulated water fluxes and groundwater velocities will be calculated from both the model used in the calibration process and the future prediction flow model. Values will be reported for instantaneous periods (e.g., hourly and daily) fluxes and longer term net and cumulative values. The results will focus on the aquifer/Columbia River interface on the eastern boundary of the model, but will also provide the regional groundwater fluxes into the model domain from the western boundary and at areas of interest within the model domain.

Groundwater velocities and streamlines with travel markers from the simulations will also be provided for selected periods.

4.5.1.4 Particle Pathway Simulations

Particle pathway (or streamline) simulations will utilize the velocities from the groundwater flow model that provides for the best-fit to the observed hydraulic head data. The CFD add-in module for the Tecplot™ program will be utilized to generate visualizations of the particle tracks.

4.5.2 Contaminant Transport Modeling

Contaminant transport modeling will be conducted to better understand movement of the uranium in the 300 Area aquifer and the flux of uranium to the Columbia River as a function of time. The following tasks will be completed as part of this contaminant transport modeling effort.

4.5.2.1 One- and Two-Dimensional Simulations

The one-dimensional simulations will help develop an understanding of uranium transport and fate focusing on interactions between the (1) vadose zone and aquifer, and (2) aquifer and the river. These simulations are fundamental to help understand the coupled processes controlling the uranium flux to the groundwater from contaminated vadose zone sediments, and from the aquifer to the river. A key consideration for the design of these simulations will be the representation of specific land use scenarios that can alter the recharge, chemistry, and uranium inventory.

The two-dimensional vertical cross-section simulations will target uranium reactive transport in a dynamic hydrologic system comprised of vadose zone, aquifer, and river components. These simulations will include the impact on uranium transport and fate of temporally varying groundwater velocities, as well as the impact of spatially variable hydrologic properties. The modeling framework will provide a reactive transport test bed to examine the evolution of the uranium groundwater plume from vadose zone sources. In this case, the partitioning of uranium between sediment and solution responds dynamically to mixing of aquifer and river waters.

4.5.2.2 Evaluation of Uranium Data for Three-Dimensional Modeling

Available sources of data on concentrations of uranium in the 300 Area vadose zone will be compiled to develop a three-dimensional conceptualization of the uranium distribution in the vadose zone. For the aquifer, this effort will build on an initial representation of uranium that was developed in 2003. It will also make use of geostatistical representations of uranium distributions in the aquifer that are being developed (Murray et al. 2004). Chemical analysis of uranium concentrations in sediment samples collected from the 300 Area have been reported in Swanson et al. (1992), DOE (1994b), Serne et al. (2002), and Zachara (2004). Other data sources will also be investigated and compiled.

This task will use EarthVision to create a three-dimensional representation of initial uranium concentrations in the aquifer and vadose zone for input to the transport model. The three-dimensional EarthVision datasets for the aquifer and vadose zone will be sampled at model node locations to provide initial conditions for the uranium transport simulations. EarthVision is currently being used for developing the hydrogeologic structure used in the 300-FF-5 STOMP groundwater flow models (White and Oostrom 2000). EarthVision will also be used to provide three-dimensional visualization of the uranium concentrations and for some simulation results. The total uranium in the aquifer and vadose zone will be calculated considering partitioning to soils. These sums will be compared to other available inventory estimates.

4.5.2.3 Integration of Science and Technology Modeling to Three-Dimensional Transport Model

An equilibrium-based surface complexation model (SCM) has been developed to describe the sorption characteristics of uranium in 300 Area sediments (Davis et al. 2004; Zachara et al. 2005). Although the SCM model has been shown to reproduce experimentally observed uranium sorption data quite well, other results (Zachara et al. 2005) show that "U(VI) release from the sediments was found to be very slow and to require extensive water volumes for even partial removal of the sorbed U(VI) plume. U(VI) desorption was found to be a kinetic and not an equilibrium process." While the equilibrium-based SCM represents a significant improvement over simple Kd-based transport models, the SCM may not be entirely appropriate for regions in which rapid transients occur, such as the zone of interaction between the river and groundwater in the 300 Area. Zachara and co-workers are, thus, developing a kinetic, multi-rate model to describe their experimental results (Liu et al. 2004). The model uses a gamma distribution function to define the multiple rates.

The initial work will develop a reaction network based on the experimental results of Serne et al. (2002), and/or Davis et al. (2004) and Zachara et al. (2005) and represent this reaction network as a set of coupled kinetic reaction equations that will be solved using STOMP. The equilibrium-based SCM reaction equations of Davis et al. (2004) and Zachara et al. (2005) will be expressed as rate equations and solved by STOMP. The multi-rate model of Liu et al. (2004) can also be readily solved by STOMP.

This task will provide:

- Integration of Science and Technology chemistry with full three-dimensional velocity fields
- Assessment of unmitigated uranium transport and fate

4.5.2.4 Construction of Three-Dimensional Transport Model

The three-dimensional transport model will be developed from the three-dimensional flow model using the STOMP simulator. Numerical simulation of advective-dispersive transport generally requires that the spatial and temporal discretization of the model conform with grid Peclet (P_n) and Courant (C_n) number constraints. An explicit, total-variation-diminishing (TVD) transport scheme is available in STOMP that eliminates the P_n number constraint. However, this scheme requires that $C_n \leq 1$. Depending on the types of reactions that are considered, Dahmkohler number (D_n) and operator-splitting error constraints may also be applicable. Therefore, the spatial and temporal discretization of the transport model will likely differ from those used for the flow model. The new grid will be tested with conservative tracer simulations prior to use in uranium transport simulations.

4.5.2.5 Limited History Matching of Uranium Measurements

This task will compare simulated uranium concentrations with selected aquifer uranium concentrations to test and refine the field-scale uranium transport model. General trends observed in semi-annual aquifer uranium concentration measurements from seasonal variations could be used for comparison with simulated values. Examples of potential tests include

- Uranium behavior at 399-1-17A during the last operational stages of the 316-5 trenches
- High concentrations near the 399-4-9 and 399-3-10 wells during lowest river stages
- Mineral depletion where bank storage is active

4.5.2.6 Simulations of Remediation Scenarios as Part of the Feasibility Study

This modeling task will be completed in conjunction with the feasibility study described in Section 4.4 and selected remedial options using either the three-dimensional transport model or Science and Technology models. For each remedial option, the appropriate model will be matched to the remedial option requirements. Natural attenuation will be simulated with the three-dimensional uranium transport model with aquifer and vadose zone initial concentrations set to values representing the present period (year ~2000 – as outlined in above tasks). Long-term simulations will be conducted using groundwater flow conductions developed for the future prediction model. Included in this effort will be a re-evaluation of the soil clean-up standard for the 300 Area.

Some remedial options may require the three-dimensional model for simulating processes such as complex pumping or injection strategies. Other remedial options may require simulations at a very fine spatial resolution (e.g., 1 meter [3.3 feet]) which would preclude the use of a large three-dimensional model for the entire 300 Area domain. Separate submodels may need to be built based on the larger scale model for these cases.

4.6 Risk Assessment Activities

The purpose of the 300-FF-5 Baseline Risk Assessment is to estimate risk to human health and the environment in the 300-FF-5 Operable Unit. The assessment will use updated information available since the *Phase 1 Remedial Investigation Report for the 300-FF-5 Operable Unit* (DOE 1994b) was published in 1994. Some of the areas to address in this updated risk assessment are changes in contaminants of concern, changes in the environment, and a change in the geographical scope of the 300-FF-5 Operable Unit. In discussing the plan for the 2005 risk assessment update, information from DOE (1994b) will be referred to as the “1994 report.” Information to be included in the updated report will be referred to as the “2005 report.”

4.6.1 Scope of Work

The spatial extent of the 300-FF-5 Baseline Risk Assessment will be the areas evaluated in the 1994 report and the groundwater beneath the outlying 300-FF-2 source sites and burial grounds (areas 618-11 and 618-10/316-4) as added in the explanation of significant difference (EPA 2000b) for the 300-FF-5 record of decision. The time frame for the 300-FF-5 baseline risk assessment update will be the period since the data were collected for the 1994 report. The 1994 report was based on data collected over four quarters in 1992. Risks to human health and the environment were evaluated using the 1992 data. Human health risk was also computed for predicted concentrations for 2018 based on a simple groundwater transport model and radioactive decay. The 2005 report will evaluate human health and ecological risk for current data, and human health and ecological risk will be calculated based on predicted concentrations for 2018.

4.6.2 Data Collection

Environmental media for which data are to be collected are determined by the human health scenarios and the ecological receptors to be evaluated. For the 1994 report, the media for which data were collected were groundwater, seep and spring water, and surface water. In addition, biota tissue concentrations were collected for use in the ecological assessment.

For the 2005 report, the media data needed are contained in the Hanford Environmental Information System (HEIS 1994). The concentrations needed are from groundwater, sediment, pore water (from aquifer tubes), and surface water. Biota tissue data needed for the ecological assessment will be used from recent monitoring activities and special studies.

4.6.3 Data Evaluation

According to the U.S. Environmental Protection Agency’s (EPA) *Risk Assessment Guidance for Superfund* (RAGS, EPA 1989) and the *Hanford Site Risk Assessment Methodology* (HSRAM, DOE 1995a), data evaluation consists of a comparison to background concentrations followed by a comparison to risk-based benchmark concentrations and applicable or relevant and appropriate requirements. In the 1994 report, a blank adjustment was included in the data evaluation process. This step will not be included in the 2005 report because blank adjustments have not been included in other risk assessments at Hanford, and it is not considered appropriate by regulators and stakeholders involved in current risk integration efforts.

In the 1994 report, background screening was based on wells that were located hydraulically upgradient of the 300 Area source operable units. However, for the 2005 report, background screening will be based on the *Hanford Site Background: Part 3, Groundwater Background* (DOE 1997).

The 1994 report performed a comparison to risk-based benchmark concentrations and contaminant-specific cleanup regulations (e.g., MTCA, WAC 173-340) for those constituents that exceeded background or in which no background existed. The applicable or relevant and appropriate requirements sources selected for the 1994 report have been reviewed and are also appropriate for the 2005 report.

4.6.4 Ecological Assessment

The ecological assessment will consist of a risk evaluation and a description of the environment for the 300-FF-5 Operable Unit. Environmental impacts in the 300-FF-5 Operable Unit will be described using information collected since the 1994 report. The Ecological Monitoring Program has been evaluating the upland and riparian regions of the 300-FF-5 Operable Unit. Results from this program are in updated revisions of the *Hanford Site National Environmental Policy Act (NEPA) Characterization* (Neitzel 2004) and in a recent report for the remediation decision support project (Downs et al. 2004).

The 1994 report evaluated chemical and radionuclide dose to terrestrial and aquatic receptors. The terrestrial receptors were evaluated by using measured tissue concentrations to compute dose to a higher food web receptor and then the resulting dose was then compared to a toxicity parameter (no-observed effect level) in order to calculate an environmental hazard quotient. The aquatic receptors were evaluated by comparing the maximum groundwater concentration to toxicity parameters (acute and chronic lowest-observed effect level). Radiological dose rate was evaluated only to a generalized set of riparian and aquatic receptors using the CRITR2 computer model and the 1992 data. No evaluation of ecological risk was performed using the predicted concentrations for 2018.

For the 2005 report, the receptors from the 1994 report will be evaluated for comparison purposes. In addition, the receptors being considered in other risk assessments and as described in MTCA will be evaluated. Chemical risk and radiological dose to terrestrial and aquatic receptors will be evaluated using the Ecological Contaminant Exposure Model (ECEM). ECEM is the ecological risk tool developed based on the Columbia River Comprehensive Impact Assessment and is currently being used in the System Assessment Capability. This model uses the same radiological dose algorithms as in CRITR2, and can also evaluate chemical risk to terrestrial and aquatic organisms. The ECEM model implements a food-web approach to calculating ecological body burdens and doses. The 2005 report will include an ecological risk assessment based on current concentrations as well as those predicted for 2005.

If possible, the 2005 report will include a comparison of modeled chemical body burdens for terrestrial receptors to measured tissue concentrations collected and reported in Patton et al. (2003), the last report of biota sampling in the 300 Area. In addition, the ecological assessment will be consistent with regulations and standards that have been updated since the 1994 report, including MTCA and the DOE Technical Standard, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE 2002).

4.6.5 Human Health Assessment

The human health assessment will consist of a comparison of risk from the 1994 report to conditions in present day. The 1994 report followed the risk assessment methodology in *Risk Assessment Guidance for Superfund* (RAGS), Volume 1, Human Health Evaluation Manual (Part A) (EPA 1989), and the *Hanford Site Baseline Risk Assessment Methodology* (HSBRAM, DOE 1991) to evaluate chemical and radiological risk to human health from 1992 data and predicted concentrations in 2018. The human health scenarios in the 1994 report included the HSBRAM industrial scenario for the 1992 data and the HSBRAM industrial, residential, recreational, and agricultural scenarios for the predicted concentrations in 2018. Groundwater was only used in the industrial scenario. The other scenarios used surface water at the 300 Area and the city of Richland water intake.

In the 1994 report, the results for the human health assessment included noncarcinogenic and carcinogenic effects. The noncarcinogenic risk characterization compared chronic daily intake of contaminants with a reference dose to calculate a hazard quotient. The carcinogenic risk characterization consisted of multiplying the intake of carcinogenic contaminants by the contaminant-specific slope factors to calculate an incremental cancer risk. Toxicity parameters (reference doses and slope factors) for these calculations are available from EPA databases such as the *Integrated Risk Information System* (IRIS, EPA 2004) and the *Health Effects Assessment Summary Tables* (HEAST, EPA 1995).

The 2005 report will conduct a similar human health assessment to that conducted for the 1994 report in order to provide a direct comparison of the results. The scenarios used in the 1994 report will be evaluated along with more recent scenarios considered in the Composite Analysis. Updated information will be used for scenarios as in the 1995 update of HSBRAM, which was re-titled *Hanford Site Risk Assessment Methodology* (HSRAM, DOE 1995). Toxicity profiles for human health assessments are constantly under review, with some profiles being updated while others may be rescinded. The 2005 report's toxicity assessment will be conducted with the most current information being used. In the case of rescinded toxicity data, the most recent quantitative information will be used, which is standard practice.

4.6.6 Integration and Coordination

The 2005 report is being coordinated with several other risk assessments at the Hanford Site. The health parameters, ecological receptors, and human health scenarios are consistent with those being considered for the Composite Analysis. Where possible, the 2005 report will be consistent with the assessments that are currently being conducted in the 300 Area (100/300 Area risk assessment and River Corridor Baseline Risk Assessment) as well as the 100-B/C pilot project and 100-NR-2 risk assessments. Specifics on ECEM were presented to these risk assessors in November 2004. The 300-FF-5 risk assessors are meeting with these other risk assessors, sharing information on health parameters, ecological receptors, and human health scenarios.

5.0 Work Plan Deliverables

The primary deliverable of the work plan is the Phase III Feasibility Study and the draft Proposed Plan. This will occur in May of 2007 as shown on the schedule in Figure 3.

In addition to the Phase III Feasibility Study and draft Proposed Plan, five interim working documents will be produced throughout the study:

- Limited Field Investigation Work Plan
- Limited Field Investigation Report
- Modeling Report
- Treatability Test Work Plan
- Treatability Test Report

The Phase III Feasibility Study will conform to the requirements of Chapter 6 of the *Guidance for Conducting Remedial Investigation and Feasibility Studies under CERCLA* (EPA 1988) and the expressed needs of DOE, EPA, and Washington State Department of Ecology. The study will provide narrative description of remedial alternatives assembled from appropriate technologies and deployed in configurations suitable to the site. The document will discuss the evaluation of alternatives according to nine criteria. The analysis will include a summary table highlighting the assessment of each alternative with respect to each of the nine criteria to assist the public and decision makers in understanding the options. Summaries of supporting information and results from investigations and modeling will accompany the feasibility study.

6.0 References

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Appendix

Remediation Technologies

Appendix

Remediation Technologies

As described in the main text of this document, an inventory of remediation technologies that could be used to treat uranium in groundwater was developed. The list of technologies that might be applied to control or treat dissolved uranium in groundwater in the 300-FF-5 Operable Unit is compiled in Table A.1. The list was composed according to zones or regimes where uranium is postulated to occur at the site as discussed in Section 2.0, page 5, of this work plan.

Table A.1. Initial Technology List – Uranium Focused[(a)]

Zone	Technology Type	Technology
Vadose Unsaturated soil between surface and water table (Zone 2)	Passive	*No Action* *Institutional Controls*
	Physical	More Extensive Excavation to Water Table Impermeable Surface Cap with Groundwater Level Control
	Chemical	Injection of reactive substance to form water barrier at water table Vadose flushing with mobilizing agent and hydraulic extraction of solution Vadose flushing with immobilizing agent-hydroxyapatite reaction Vadose flushing with colloidal ZVI Vadose flushing with polyphosphate Vadose flushing with dithionite solution
	Biological	Vadose flushing with calcium citrate & sodium phosphate Temporary Bio-Flushing to Anaerobicly Stabilize Uranium
Smear Unsaturated soil occasionally wetted by underlying groundwater (Zone 3)	Passive	*No Action* *Institutional Controls*
	Physical	Selective Excavation to Water Table Pressure Grout Injection at Water Table with dense push rod well pattern
	Chemical	Injection of reactive substance to form water barrier at water table • Sealing of soil formation by directed gypsum crystallization • In-situ formation of $Fe(OH)_3$ precipitates • Immobilization of heavy metals by oversaturated $Ca(OH)_2$-grouts • Immobilization by $Al(OH)_3$ producing grouts • Immobilization by in-situ $CaCO_3$ crystallization • Immobilization of heavy metals by directed and controlled $BaSO_4$ precipitation Inject LNAPL with mobilizing agent and subsequent extraction of LNAPL Inject LNAPL with immobilizing agent-hydroxyapatite reaction Inject LNAPL with colloidal ZVI Inject LNAPL with polyphosphate Inject LNAPL with dithionite solution Inject LNAPL with calcium citrate & sodium phosphate

Table A.1. (contd)

Zone	Technology Type	Technology
Smear Unsaturated soil occasionally wetted by under-lying groundwater	Biological	Temporary Bio-Flushing to Anaerobicly Stabilize Uranium Anaerobic In-situ Reactive Zone
Saturated Groundwater (Zone 4)	Passive	*No Action* *Institutional Controls* and Monitoring Monitored Natural Attenuation
	Physical	*Selective Hydraulic Containment* *Selective Hydraulic Containment with Water In-situ Flushing* *Selective Slurry Wall Containment* *Selective Slurry Wall Containment with Minimal Extraction* *Selective Slurry Wall Containment with Water In-situ Flushing* Selective Soil Freezing Containment Barrier Selective Excavation into aquifer *Extensive Hydraulic Containment* *Extensive Hydraulic Containment with Selective Water In-situ Flushing* *Extensive Slurry Wall Containment* *Extensive Slurry Wall Containment with Minimal Extraction*
	Chemical	Permeable Reactive Barrier-Zero Valent Iron Permeable Reactive Barrier-Amorphous Ferric Oxyhydroxide Permeable Reactive Barrier-Hydroxyapatite Permeable Reactive Barrier-Zeolite In-situ Reactive Barrier-injected polyphosphate DART Emplacement of ZVI and apatite pellets in wells In-situ Reactive Barrier-Nanoparticle injection Colloidal ZVI Injection Selective In-situ Area-wide Hydraulic Chemical Stabilization • In-situ formation of Fe(OH)3 precipitates • Immobilization by Al(OH)3 producing grouts • Immobilization of heavy metals by directed and controlled BaSO4 precipitation Selective Reactive Barrier Wall • Sealing of soil formation by directed gypsum crystallization • Immobilization of heavy metals by oversaturated Ca(OH)2-grouts • Immobilization by Al(OH)3 producing grouts • Immobilization by in-situ CaCO3 crystallization In-situ Reactive Barrier:hydroxy-apatite sequestration In-situ Redox Manipulation-dithionite injection
	Biological	Microbial dissimilatory reduction of U(VI) Anaerobic In-situ Reactive Zone
(a) Note: *Italicized* entries are technologies that were considered in 1994 Phase I and II Feasibility Report (DOE 1994).		

These technologies are discussed in greater detail in the following sections of this appendix. This initial list of technologies was reduced by evaluating the process option with respect to technical implementability. Table A.2 summarizes the technical selection process.

Table A.2. Initial List of Remediation Alternatives

Zone	Technology Type	Technology	Technically Implementable?	Rationale	Retain for Further Consideration?
Vadose	Passive	No Action	Yes		
	Physical	More Extensive Excavation to Water Table	Yes	Further excavation possible	Yes
		Impermeable Surface Cap with Groundwater Level Control	No	Wide-area hydraulic control not feasible due to very high permeablilities. Large rocks preclude cut-off walls.	
	Chemical	Injection of reactive substace to form water barrier at water table	Yes	Physically feasible. Agent not yet identified.	Yes
		Vadose flushing with mobilizing agent and hydraulic extraction of solution	Yes	Consider as a groundwater technology because agent collection will be in groundwater.	Yes, as groundwater technology
		Vadose flushing with immobilizing agent-hydroxyapatite reaction	Yes	Consider as a groundwater technology because hydroxyapatite will likely be applied to related saturated zone.	Yes, as groundwater technology
		Vadose flushing with colloidal ZVI	No	ZVI most appropriate for groundwater not unsaturated soil. Nanoparticle ZVI will be considered as groundwater technology.	
		Vadose flushing with polyphosphate	Yes	Polyphosphate is a likely candidate reagent for apatite formation technology. Consolidate with hydroxyapatite technology investigations.	Yes, as groundwater technology
		Vadose flushing with dithionite solution	Yes	Technology is proven but delivery of dithionite to unsaturated soil not developed. Consider under a generic technology of "Pressure Injection of Permeable Agent"	Yes, as Pressure Injection of Permeable Agent
	Biological	Vadose flushing with calcium citrate & sodium phosphate	Yes	A form of apatite technology, however delivery technology not developed. Consolidate with hydroxapatite technology investiagtions in groundwater.	Yes, as groundwater technology
		Temporary Bio-Flushing to Anaerobicly Stablize Uranium	No	Maintenance of biologically reduced zone problematic.	
Smear	Passive	No Action	Yes		Yes
	Physical	Selective Excavation to Water Table	No	The smear zone is by definition thin and wide-spread. Excavation to access smear zone requires impractical volume of soil handling.	
		Pressure Grout Injection at Water Table with dense push rod well pattern	No	Efficacy of technology dependent upon site conditions. If smear zone is widespread, grout injection is too localized be effective.	
	Chemical	Injection of reactive substace to form water barrier at water table	Yes	Identity of barrier forming reactive agent not known. Retain for further consideration.	Yes
		Inject LNAPL with mobilizing agent and subsequent extraction of LNAPL	No	LNAPL carrier has not yet been developed.	
		Inject LNAPL with immobilizing agent-hydroxyapatite reaction	No	LNAPL carrier has not yet been developed.	
		Inject LNAPL with colloidal ZVI	No	LNAPL carrier has not yet been developed.	
		Inject LNAPL with polyphosphate	No	LNAPL carrier has not yet been developed.	
		Inject LNAPL with dithionite solution	No	LNAPL carrier has not yet been developed.	
	Biological	Inject LNAPL with calcium citrate & sodium phosphate	No	LNAPL carrier has not yet been developed.	
		Temporary Bio-Flushing to Anaerobicly Stablize Uranium	No	Maintenance of biologically reduced zone problematic.	
		Anaerobic In-situ Reactive Zone	No	Maintenance of biologically reduced zone problematic.	
Saturated	Passive	No Action	Yes		Yes
		Institutional Controls	Yes	Institutional Controls and Monitoring is the present interim remedy.	Yes
		Monitored Natural Attenuation	Yes		Yes
	Physical	Selective Hydraulic Containment	Yes	Consolidate into Some form of Hydraulic Containment	Yes
		Selective Hydraulic Containment with Water In-situ Flushing	Yes	Consolidate into Some form of Hydraulic Containment	Yes
		Selective Slurry Wall Containment	No	Large rocks preclude slurry wall construction.	
		Selective Slurry Wall Containment with Minimal Extraction	No	Large rocks preclude slurry wall construction.	
		Selective Slurry Wall Containment with Water In-situ Flushing	No	Large rocks preclude slurry wall construction.	
		Selective Excavation into aquifer	No	Large rocks and excavation stability issues are problematic.	
		Extensive Hydraulic Containment	Yes	Consolidate into Some form of Hydraulic Containment	Yes
		Extensive Hydraulic Containment with Selective Water In-situ Flushing	Yes	Consolidate into Some form of Hydraulic Containment	Yes
		Extensive Slurry Wall Containment	No	Large rocks preclude slurry wall construction.	
		Extensive Slurry Wall Containment with Minimal Extraction	No	Large rocks preclude slurry wall construction.	
	Chemical	Pemeable Reactive Barrier-Zero Valent Iron	No	Excavation of barrier trench precluded by large rocks.	
		Pemeable Reactive Barrier-Amorphus Ferric Oxyhydroxide	No	Excavation of barrier trench precluded by large rocks.	
		Pemeable Reactive Barrier-Hydroxyapatite	No	Excavation of barrier trench precluded by large rocks.	
		Pemeable Reactive Barrier-Zeolite	No	Excavation of barrier trench precluded by large rocks.	
		In-situ Reactive Barrier-injected polyphosphate	Yes	Rename into generic technology of Hydroxy-apatite sequestration.	Yes
		DART Implacement of ZVI and apatite pellets in wells	Yes	Separate reagents and combine into Hydroxy-apatite sequestration and into In-situ Reactive Barrier by Nanoparticle/colloidal injection.	Yes
		In-situ Reactive Barrier-Nanoparticle injection	Yes	Nanoparticle composition is unspecified, but zero-valent iron is the principal candidate.	Yes
		Colloidal ZVI Injection	Yes	Combine with In-situ Reactive Barrier by Nanoparticle/colloidal injection.	Yes
		In-situ Reactive Barrier-calcium citrate & sodium phosphate injection	Yes	Rename into generic technology of Hydroxy-apatite sequestration.	Yes
		In-situ Redox Manipulation by dithionite injection	Yes	Effective if sufficient iron available.	Yes
	Biological	Microbial dissimilatory reduction of U(VI)	Yes	Combine into general technology of In-situ Uranium Bioreduction.	Yes
		Anaerobic In-situ Reactive Zone	Yes	Combine into general technology of In-situ Uranium Bioreduction.	Yes

A.1 Saturated Zone Remedial Technologies

Screening the initial prospective treatment technologies for the saturated groundwater zone according to effectiveness, implementability, and cost, reduced the number of options for treating dissolved uranium in groundwater within the saturated zone. Table A.3 presents nine technologies applicable to uranium in saturated soil that have been retained for a more thorough screening evaluation.

Table A.3. Candidate Technologies for Further Consideration Uranium in in Groundwater in Saturated Soil

1. No Action
2. Institutional Controls and Monitoring
3. Monitored Natural Attenuation
4. Some Form of Hydraulic Containment (Pump and Treat)
5. In-Situ Reactive Barrier by Nanoparticle/colloidal injection
6. Hydroxy-Apatite Sequestration
7. In-Situ Redox Manipulation by Dithionite Injection
8. Flushing with Mobilizing Agent
9. In-Situ Uranium Bioreduction

A brief description of each policy or technology is presented to provide a basis of comparison. It should be noted that some or all of the technologies will be combined simultaneously or sequentially later to formulate remediation alternatives for the feasibility study.

1. No Action

No action is a management alternative required by the National Contingency Plan [40 CFR 300.430(e)(7)(iii)] for the purpose of comparison with remediation alternatives. Under this alternative, no actions would be taken to remediate the groundwater contaminated with uranium. Occasional groundwater monitoring might be applied to track changes in groundwater quality, but no administrative controls would be implemented.

2. Institutional Controls and Monitoring

Institutional controls are actions that restrict access to contaminated groundwater or hydro-geographic features, such as springs, riverbanks and river bottoms that might be affected or contacted by contaminated groundwater. Thus, access restrictions and a long-term monitoring program would be implemented as part of this action. Access restrictions would consist of deed restrictions, groundwater well controls and protected wellhead structures to prevent contact with contaminated groundwater. The shoreline of the Columbia River and river sediments affected by uranium contamination from the groundwater would be fenced off and administrative controlled to prevent fishing, water contact, or physical access by persons to river shoreline or sediments known to be affected by uranium in groundwater. Long-term groundwater quality monitoring and benthic and shoreline monitoring of the Columbia River would be used to define exclusion areas. This policy option is the present response at the 300-FF-5 Operable Unit.

3. Monitored Natural Attenuation

Monitored natural attenuation involves the biodegradation, dispersion, dilution, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem. Natural attenuation is a contamination management strategy of allowing and facilitating ongoing natural processes reduce the risk of the contaminant to potential receptors. Uranium is not subject to any natural destructive process other than radioactive decay over time. However, the concentration of the uranium is chemically subject to non-biological processes such as dispersion, sorption or precipitation that might reduce uranium concentrations in groundwater over time. Because of the radioactive persistence of uranium and the complex geochemical equilibria of uranium, it is more difficult to predict the long-term behavior of dissolved uranium plumes in groundwater than the more volatile, reactive organic chemical contaminants. Thus, it is important to have a thorough understanding of the operant geophysical attenuation mechanisms such as advection, dispersion, dilution from recharge, precipitation and sorption. Detailed and comprehensive site characterization is required to adequately understand and evaluate the applicability of these processes at the site.

Long-term monitoring of water quality and flows as well as imposition and maintenance of certain institutional controls may be a part of a successful natural attenuation program. However, such monitoring and controls are ancillary to the actual attenuation processes.

To support remediation by natural attenuation, the proponent must scientifically demonstrate that degradation of site contaminants, particularly uranium, is occurring at rates sufficient to be protective of human health and the environment.

4. Pump and Treat

Some form of hydraulic containment or control may assist in managing the dissolved phase plume in the groundwater. Such control is commonly affected by extraction of groundwater and treatment of the withdrawn groundwater. The hydraulic control may be applied to intercept or contain, reduce concentration or mass of the contaminant or manage water level. Because such pumping creates an area of reduced hydraulic head, the flow rate and flow direction of the groundwater may be manipulated to retard the spread of the dissolved contaminant. The extent of the deployment may be focused on selected areas or spread over an extensive area. The depth of the groundwater affects the cost of the wells and pumping costs. The depth to groundwater at the 300-FF-5 Operable Unit is approximately 10.7 meters (35 feet) below ground surface. The effectiveness of the groundwater pumping is a function of the quantity of water pumped and the horizontal and vertical location of the withdrawal via the extraction wells. The permeability of the saturated soils will control the spacing and effectiveness of extraction wells. One should note that as pumping progresses and the concentration of the contaminant declines over time in the region near the well, the effectiveness of the pumping decreases.

The extracted groundwater is generally treated at the ground surface in a water treatment facility. Dissolved uranium in water is removed from the water by chemical precipitation or ion exchange. The combination of precipitation/flocculation and sedimentation is a well-established technology for dissolved uranium removal from groundwater. This technology pumps groundwater through extraction wells and then treats it to precipitate uranium and other heavy metals. Typical removal of uranium employs precipitation with hydroxides, carbonates, or sulfides. Hydroxide precipitation with lime or sodium hydroxide is the most common choice. Generally, the precipitating agent is added to water in a rapid-mixing tank along with flocculating agents such as alum, lime, and/or various iron salts. This mixture then flows to a flocculation chamber that agglomerates particles, which are then separated from the liquid phase in a sedimentation chamber. Other physical processes, such as filtration, may follow.

Filtration isolates previously precipitated solid particles by running a fluid stream through a porous medium. The driving force is either gravity or a pressure differential across the filtration medium. Pressure differentiated filtration techniques include separation by centrifugal force, vacuum, or positive pressure. The chemicals are not destroyed; they are merely concentrated, making reclamation possible. Parallel installation of double filters is recommended so groundwater extraction or injection pumps do not have to stop operating when filters backwashed.

Ion exchange is a process whereby the toxic ions are removed from the aqueous phase in an exchange with relatively innocuous ions (e.g., NaCl) held by the ion exchange material. Modern ion exchange resins consist of synthetic organic materials containing ionic functional groups to which exchangeable ions are attached. These synthetic resins are structurally stable and exhibit a high exchange capacity. They can be tailored to show selectivity towards specific ions. The exchange reaction is reversible and concentration dependent; the exchange resins are regenerable for reuse. The regeneration step leads to a 2% to 10% waste stream that must be treated separately.

In all implementations of pump and treat, the uranium is concentrated into a solid or liquid solution that requires stabilization and possible off-site transport and disposal.

5. In-Situ Reactive Barrier by Nanoparticle/Colloidal Injection

Permeable reactive barriers (PRBs) could be used to react the dissolved uranium either in an interception mode to protect the Columbia River of isolate localized “hot spots” of contamination in the groundwater. Typically, permeable reactive barriers are constructed by the excavation of trenches. An important limitation for application of a permeable barrier in the 300 Area is the depth of emplacement involved. The depth from the ground surface to the base of the unconfined aquifer is approximately 30.48 meters (100 feet). This depth is greater than the capability of present trenching technologies (excavators are limited to maximum depths of about 24 meters [79 feet]). In addition, the Hanford formation is unconsolidated sand and gravel and it would be difficult to maintain an open trench during construction. Pumping of water from the trench would also be necessary as excavation continued into the saturated zone. An attractive alternative to trenching is the emplacement of a PRB through developing in situ emplacement approaches, which are much less restrictive in terms of depth of emplacement. In situ emplacement technologies also minimize the need for disposal of contaminated sediments associated with excavation of the barrier.

A new technology in development uses very fine particle or colloidal suspensions of reactive media to place or construct a reactive barrier. One of the most effective reactive media for treatment of dissolved uranium is zero-valent iron (ZVI). Abiotic reduction and immobilization can be achieved through the use of zero valent iron emplaced in permeable reactive barriers. ZVI produces a low oxidation potential in groundwater, which results in the precipitation of low-solubility products of certain reduced contaminants such as uranium and chromium. In carbonate-dominated groundwater at neutral to slightly alkaline pH values, U(VI) is reduced to U(IV) and precipitates as uraninite or a less crystalline precursor as indicated by the reaction:

$$Fe^{0}_{(ZVI)} + UO_2(CO_3)_2^{2-} + 2\ H^+ = UO_{2(solid)} + 2\ HCO_3^- + Fe^{2+}$$

This reaction removes the dissolved uranium from the groundwater and precipitates the uranium within the volume of the reactive barrier. ZVI-based permeable reactive barriers have been installed for treatment of uranium contamination in groundwater at several sites, notably at the U.S. Department of Energy (DOE) Oak Ridge Y-12 Plant in Tennessee, the uranium mill tailings at Durango in Colorado, and at Monticello and Fry Canyon in Utah. These PRBs have been in operation only a few years, but have provided some useful information related to performance. Short-term performance appears to be good. Longevity, which is important to assessing the cost effectiveness of the ZVI PRB, cannot yet be determined. Longevity may potentially be reduced by dissolution of the iron, mineral precipitation leading to permeability reduction, and passivation of the ZVI from alteration of the iron grain surfaces.

A possible alternate methodology to trenching for emplacement of a ZVI barrier is the in situ injection of colloidal iron powders. This technology is sometimes referred to as nano-particle technology because of the very small size of the particles. Injection of nano-particle iron in suspension is problematical owing to the high density of iron. Suspensions can be prepared, however, using polymer additives that permit injection into porous media. The powdered ZVI is relatively expensive ($7 per pound), but may be economical for focused applications in limited amounts.

Further treatability evaluation and pilot testing is required to fully evaluate this technology.

6. Hydroxy-Apatite Sequestration

Adsorption is a process whereby an aqueous chemical species attaches to a solid surface. Most adsorption reactions are reversible and occur at relatively rapid rates, and a potential for contaminant breakthrough exists if the exchange capacity is exceeded or for desorption if more dilute solutions pass over the adsorptive surface. Some adsorption reactions are specific for particular species while other reactions are less specific and a variety of ions compete for attachment sites.

Uranium (VI) has been shown to be immobilized from aqueous solutions through interaction with calcium hydroxyapatite [$Ca_5(PO_4)_3OH$]. Uranium is apparently removed by formation of uranyl phosphate precipitates on the hydroxyapatite surface at higher concentrations of uranium and by adsorption at lower concentrations. Precipitation of uranyl phosphate is likely to be an irreversible process, but may result in passivation or blocking of reactive surface sites. Specific forms of hydroxyapatite available for use in permeable reactive barriers include bone meal, bone charcoal, and phosphate.

A significant challenge to using this technology in the 300-FF-5 aquifer is emplacing the hydroxyapatite. Most work involving development and deployment of apatite permeable reactive barriers has focused on placement of palletized bone char apatite in trenches because of its high permeability. However, such a trench configuration encounters the excavation problems at depth that limit the ZVI barrier technology.

Formation of an in situ permeable reactive barrier with apatite may be possible using an approach proposed by Moore et al. (in press). This method involves injection of a solution of calcium citrate and sodium phosphate into the subsurface. As indigenous microorganisms mineralize the citrate, calcium is released and combines with phosphate to form hydroxyapatite. This approach has been shown to immobilize Sr-90 in the laboratory where the mechanism of strontium sorption is reported to be by substitution of strontium for calcium into the hydroxyapatite lattice. The formation of an apatite in situ PRB by the citrate-phosphate approach should also be applicable to uranium remediation.

Further treatability evaluation and pilot testing is required to fully evaluate this technology.

7. In Situ Redox Manipulation by Dithionite Injection

Another approach to achieving uranium remediation by abiotic chemical reduction is through the in situ redox manipulation (ISRM) approach. This technology generates a permeable reactive barrier *in situ* through the injection of a dithionite solution that reduces structural iron in the sediments to adsorbed Fe(II) and Fe(II)-carbonate. Redox-sensitive contaminants in a groundwater plume are then immobilized as they migrate through the treated zone. Contaminants that are candidates for this approach include hexavalent chromium, chlorinated solvents, and uranium. Hexavalent chromium is readily reduced to Cr(III), which is less toxic, essentially insoluble, and not easily re-oxidized. Reduction of U(VI) to U(IV) is not as easily accomplished, however, and is subject to re-oxidation and possible remobilization. Laboratory testing activities conducted at Pacific Northwest National Laboratory (PNNL), however, suggest that uranium concentrations released will be low after the barrier is exhausted because the associated oxidation and dissolution reactions are slow.

An ISRM permeable reactive barrier has been successfully installed in the 100-D Area at the Hanford Site where it is being used to treat a chromium groundwater plume. Recent monitoring results indicate premature breakthrough of chromium is occurring in certain sections of the barrier. It is postulated that these may be zones of higher permeability, possibly associated with gravel layers or channels. These materials are generally lower in available reactive iron content and it has been suggested that this is responsible for the preferential breakthrough observed. It has been proposed that selective injection of colloidal ZVI be undertaken in those sections of the barrier as a means of increasing the reactive iron content. A combination of the ISRM and colloidal ZVI injection technologies may be a feasible approach for PRB installation in the 300 Area.

Further evaluation of ISRM by dithionite injection will require identification of whether sufficient iron is present in saturated soil materials in the 300 Area. Further treatability evaluation and pilot testing is required to determine the applicability of this technology in the 300-FF-5 Operable Unit.

8. Flushing with Mobilizing Agent

The presence of dissolved uranium within the groundwater in the 300-FF-5 Operable Unit may be correlated to adsorbed or solid phase deposits of uranium within the saturated soils of the aquifer. Should further characterization or remediation efforts determine that such a sorbed inventory of uranium provides a continuing source of dissolved uranium in the groundwater, this technology may be applicable.

Flushing with a mobilizing agent involves the injection of chemicals that by modifying the pH, eh, or solubility of sorbed uranium on aquifer soils causes uranium to dissolve into the water. This action accelerates an ongoing dissolution process and if coupled with either hydraulic extraction or a down gradient reactive barrier could accelerate the cleanup of the aquifer. Careful application of the mobilizing agent would be required to minimize harmful effects on down gradient or river receptors.

Further treatability evaluation and pilot testing is required to fully evaluate this technology.

9. In Situ Uranium Bio-Reduction

It may be possible to establish an in-situ permeable reactive barrier within the aquifer of the 300-FF-5 Operable Unit. Facultative or anaerobic consortia of bacteria would be applied with a carbon source, such as lactate or acetate. Utilization of Fe(III) or other metal such as Uranium (VI) in the aquifer as a metabolic electron acceptor would reduce the iron and uranium. The dissolved uranium would be precipitated by the bacterial action. Long-term immobilization of uranium by this approach may require periodic rejuvenation of microorganisms and maintenance of reducing conditions by injection of carbon substrate.

Further treatability evaluation and pilot testing is required to fully evaluate this technology.

A.2 Lower Unsaturated Soils

Unsaturated soils above the water table where releases of contamination have occurred such as beneath former ponds and cribs as well as associated with pipeline releases provide a possible source for continuing contamination of the groundwater. This zone is sometimes called the “smear zone” in the context where soluble uranium is deposited during periods of high water level. Lower unsaturated soils above the groundwater may be addressed by remedial actions in so far as such soils contribute to the contamination in groundwater. If groundwater modeling and/or treatability investigation indicates that contamination in lower unsaturated soils contribute to groundwater contamination, Table A.4 presents four technologies that could be assembled into remedial technologies that the feasibility study could evaluate. Cleanup actions could be applied to unsaturated soils above the water table where residual uranium on the soils are shown to pose a significant threat to expeditious attainment of groundwater cleanup goals.

Table A.4. Remedial Technologies for Uranium in Unsaturated Soils Contributing to Groundwater Contamination

1. No Action
2. Selective Excavation to Water Table
3. Pressure Injection of Permeable Agent
4. Injection of Reactive Substance to Form Impermeable Barrier

A brief description of possible technologies that could be considered is presented. It should be noted that some or all of the remedial actions could be combined in simultaneously or sequentially during a remedial program at the site.

1. No Action

No action is a consideration required by the National Contingency Plan [40 CFR 300.430(e)(7)(iii)] for the purpose of comparison with remediation alternatives. Under this approach, no actions would be taken to remediate soils immediately above the water table that are contaminated with uranium. Occasional groundwater monitoring might be applied to track changes in groundwater quality. Administrative controls such as deed restrictions to prohibit excavations into the soil below 4.6 meters (15 feet) from ground surface would attempt to control exposure from future intrusion.

2. Selective Excavation to Water Table

Excavation of contaminated soil to approximately 10.7 meters (35 feet) below ground surface and removal of a relatively thin horizon of contaminated soils would be analogous to a surface mining operation. Except for areas where contamination is present throughout the whole soil column, a relatively large proportion of the soil removed would be uncontaminated and temporarily stockpiled as overburden. Excavation would be conducted during periods of lowest groundwater levels for the purpose of maximizing recovery. The contaminated soil immediately above and at the water table would be removed using conventional excavation equipment such as dragline buckets, dewatered and disposed. Disposal would be directed to either onsite or offsite locations according to the volume and radioactivity of the excavated soil.

The excavation would be focused on areas where prior characterization indicates high probability of concentrations, generally at or near uranium effluent release points such as former ponds, cribs, or areas known to have high uranium concentrations at the water table. Following removal of contaminated soil at or near the water table, the excavation would be back filled and compacted.

3. Pressure Injection of a Permeable Agent

Rather than excavate and remove uranium in lower unsaturated zone soil, this approach applies a chemical agent to stabilize and prevent dissolution or release of uranium in soil near the water table into the groundwater. The advantage of this approach is that chemical fixation of the contaminant could be effected in situ with drilling technology. Costly and difficult excavation would not be required to mitigate the threat to groundwater.

The chemical process of the stabilizing chemical agent remains to be determined. Several candidate processes could be considered. In situ gaseous reduction and bioreduction are candidate processes.

In situ gaseous reduction (ISGR) uses a hydrogen sulfide/nitrogen gas mixture to reduce contaminants and sediment-associated iron. For contaminants such as chromate, uranium, and technetium, the reduced species are significantly less mobile than the oxidized species. With the reduction of sediment-associated iron, the ISGR technology creates a reducing zone within the subsurface that will continue to reduce contaminants or other oxidants (e.g., oxygen) that migrate into the treatment zone until the reducing capacity becomes depleted. The capacity of the reducing zone is a function of the reducible iron content in the sediment.

Multiple wells could be used to apply a liquid or gas-phase carbon and nutrient source to promote anaerobic biological activity. Anoxic processes in unsaturated soils could be induced by introducing a gaseous substrate such as small chain alkanes/alkenes (e.g., propane, propene) that serves as a substrate for microorganisms under the existing aerobic conditions in the aquifer. As the microorganisms consume the organic substrate, oxygen is depleted. The bacterial biomass that is produced during this process decays under the anoxic conditions caused by the previous activity and can be a carbon source to other bacteria that thrive under anoxic conditions. Thus, it may be feasible to devise a bioreduction process in unsaturated soils whereby a small chain alkane/alkene such as propane or propylene is initially distributed to create anoxic conditions and build up a reserve of organic carbon in the sediments. Hydrogen gas could then be distributed to serve as a substrate for anoxic microbial reactions including the reduction of uranium, iron, and manganese. Further treatability evaluation and pilot testing may be required to fully evaluate this technology.

4. Injection of Reactive Substance to Form Impermeable Barrier

This remedial approach applies a physical rather than chemical agent to the subsurface to reduce the mobility of uranium in the lower unsaturated soils near the water table. The agent could be a grout, a polymer that forms a solid over time or other form of physical barrier that could be applied to form a horizontal barrier.

In situ grouting is a type of in situ solidification and stabilization technology. The objective of this technology is to immobilize contaminants through a combination of chemical reactions and/or physical encapsulation. The desired end product resulting from the solidification process is a monolithic block of waste with high structural integrity and low leaching characteristics. The encapsulation of contaminants within the monolith reduces the surface area exposed to liquids (because of the low permeability of the monolith), thus reducing the potential for leaching. Stabilization effects result from chemically immobilizing (binding) contaminants or from a reduction in contaminant solubility (e.g., caused by a change in oxidation state or pH).

There is a wide variety of choice in grout formulation. Usually, the grout formulation is tailored to the site-specific conditions and project needs in terms of grout workability, strength of the cured grout, contaminant binding/leaching, type of soil, moisture content, etc. Portland cement is a commonly used grout material, but other materials (e.g., organic grouts, inorganic grouts, polymers, etc.) are available. Typical additives include bentonite, zeolites, fly ash, cement kiln dust, and various silicates.

Mixing may be achieved using augers, high pressure jetting, or low-pressure permeation. The effectiveness of the mixing techniques depend on specific site conditions, soil characteristics, depth required etc. Grouting performance is highly dependent on mixing efficiency. It is difficult to verify whether mixing is sufficient when applied in situ.

Jet grouting involves injecting a grout mixture at very high pressures (up to 5,000 to 6,000 pounds per square inch) and velocities (as great as 800 to 1,000 ft/s) into the pore spaces of the soil or rock. The jetted grout cuts, replaces, and mixes the soil with cementing material to form a column (rotating the drill rod as it is removed). The soil structure is destroyed as grout and soil are mixed, forming a homogeneous mass. Jet grouting can be used in soil types ranging from gravel to clay, but the soil type can alter the diameter of the grout column).

A.3 References

40 CFR 300.430(e)(7)(iii). "National Oil and Hazardous Substances Pollution Contingency Plan." U.S. Environmental Protection Agency, *Code of Federal Regulations.*

DOE. 1994. *Phase I and II Feasibility Study Report for the 300-FF-5 Operable Unit*. DOE/RL-93-22, U.S. Department of Energy, Richland, Washington.